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Green and biodegradable surfactants synthesis and applications

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Abstract

Green and biodegradable surfactants have emerged as sustainable alternatives to conventional petrochemical-based surfactants due to growing environmental concerns, regulatory pressures, and the demand for eco-friendly products. These surfactants are derived from renewable resources such as plant oils, sugars, and microbial biomass, and are designed to exhibit low toxicity, high biodegradability, and excellent surface-active properties. This paper reviews the synthesis routes of green and biodegradable surfactants, including microbial biosynthesis, enzymatic processes, and green chemical synthesis methods aligned with the principles of green chemistry. Emphasis is placed on structure–property relationships, physicochemical performance, and environmental safety aspects. The paper further discusses a wide range of applications in personal care, household detergents, agriculture, pharmaceuticals, enhanced oil recovery, and environmental remediation. Challenges related to large-scale production, cost competitiveness, and performance optimization are also highlighted. Overall, green and biodegradable surfactants represent a promising pathway toward sustainable industrial practices and environmental protection.

Keywords: Green surfactants, Biodegradable surfactants, Biosurfactants, Sustainable synthesis, Environmental applications

Introduction

Surfactants are indispensable components of modern industrial and consumer products due to their ability to reduce surface and interfacial tension, enabling processes such as emulsification, detergency, wetting, and dispersion. Conventionally, most surfactants are synthesized from petrochemical feedstocks and are widely used in detergents, cosmetics, pharmaceuticals, agrochemicals, petroleum recovery, and numerous industrial formulations. Despite their functional efficiency and low production cost, conventional surfactants pose serious environmental concerns, including poor biodegradability, aquatic toxicity, bioaccumulation, and long-term persistence in ecosystems. The continuous discharge of these synthetic surfactants into water bodies has been associated with foam formation, disruption of aquatic life, and adverse effects on soil and human health. Growing global awareness of environmental sustainability, coupled with stringent regulatory frameworks and consumer preference for eco-friendly products, has accelerated the search for greener alternatives. In this context, green and biodegradable surfactants have gained significant attention as sustainable substitutes capable of delivering comparable or superior performance with reduced ecological impact. These surfactants are typically derived from renewable resources such as plant oils, carbohydrates, amino acids, and microbial metabolites, and are designed to undergo rapid biodegradation into non-toxic by-products. Green surfactants encompass biosurfactants produced via microbial fermentation as well as bio-based surfactants synthesized through environmentally benign chemical or enzymatic routes that follow the principles of green chemistry. Their advantages include low toxicity, high biocompatibility, effectiveness under extreme conditions, and reduced carbon footprint. However, challenges related to production cost, scalability, consistency, and formulation compatibility still limit their widespread industrial adoption. Therefore, a comprehensive understanding of their synthesis strategies, structure–property relationships, functional performance, and application potential is essential. This paper aims to provide an integrated overview of green and biodegradable surfactants, focusing on their synthesis methods and diverse applications across industrial sectors, while highlighting environmental benefits, technological challenges, and future research directions for advancing sustainable surfactant technology.

Scope of the Study

The scope of this study encompasses a comprehensive examination of green and biodegradable surfactants with particular emphasis on their synthesis methods and practical applications across various industries. The study focuses on surfactants derived from renewable and sustainable resources, including microbial biosurfactants and bio-based chemically synthesized surfactants developed using green chemistry principles. It covers key synthesis pathways, physicochemical properties, biodegradability, and environmental safety aspects that determine their suitability as alternatives to conventional surfactants. Additionally, the study explores major application areas such as personal care, household detergents, agriculture, pharmaceuticals, petroleum recovery, and environmental remediation, highlighting performance efficiency and sustainability benefits. Comparative insights with petrochemical surfactants are included to assess advantages and limitations. While economic feasibility and large-scale production challenges are discussed, detailed process engineering and commercial scale-up studies are beyond the scope. Overall, the study aims to provide a focused academic framework to support future research and sustainable industrial adoption of eco-friendly surfactants.

Purpose of the Study

The purpose of this study is to critically examine green and biodegradable surfactants as sustainable alternatives to conventional petrochemical-based surfactants, with a focus on their synthesis strategies and application potential. The study aims to highlight the environmental and functional advantages of surfactants derived from renewable resources and produced through green chemistry and biotechnological approaches. By analyzing various synthesis routes, the research seeks to understand how molecular structure and production methods influence surface activity, biodegradability, and eco-toxicity. Another key purpose is to evaluate the effectiveness of these surfactants across diverse sectors such as personal care, household cleaning, agriculture, pharmaceuticals, petroleum recovery, and environmental remediation. The study intends to identify existing challenges related to cost, scalability, and performance consistency, thereby providing insights into research gaps and future directions. Overall, the study seeks to support informed decision-making and promote the development and adoption of environmentally responsible surfactant technologies.

Background and Definition of Surfactants

Surfactants, or surface-active agents, are chemical compounds that reduce surface and interfacial tension by accumulating at the interface between two immiscible phases such as liquid–liquid, liquid–solid, or liquid–gas systems. Structurally, surfactants are characterized by their amphiphilic nature, consisting of a hydrophilic (water-attracting) head group and a hydrophobic (water-repelling) tail. This dual affinity enables surfactants to facilitate essential processes such as emulsification, detergency, wetting, dispersion, and solubilization. Historically, surfactants were derived from natural sources like soaps produced from fats and oils; however, industrial advancement led to the large-scale production of synthetic surfactants from petrochemical feedstocks. These materials became integral to a wide range of applications, including household detergents, personal care products, pharmaceuticals, agriculture, textiles, food processing, and petroleum industries. Due to their versatility and effectiveness, surfactants play a critical role in modern industrial operations, although their widespread use has also raised concerns regarding environmental persistence and ecological safety.

Fundamentals of Surfactant Chemistry

- **Molecular Structure and Amphiphilicity**

Surfactants are defined by their unique amphiphilic molecular structure, which consists of two distinct regions: a hydrophilic (polar) head group and a hydrophobic (nonpolar) tail, typically a hydrocarbon or fluorocarbon chain. This dual affinity drives surfactant molecules to adsorb at interfaces such as air–water, oil–water, or solid–liquid boundaries, where they orient themselves to minimize free energy. The hydrophilic head interacts with aqueous phases through ionic or hydrogen-bonding interactions, while the hydrophobic tail avoids water and associates with nonpolar substances. This amphiphilic nature is the fundamental reason surfactants can stabilize emulsions, disperse insoluble materials, and enhance wetting and cleaning processes.

- **Critical Micelle Concentration (CMC) and Surface Activity**

As surfactant concentration in a solution increases, molecules initially accumulate at interfaces, leading to a reduction in surface or interfacial tension. Once the interface becomes saturated, additional surfactant molecules aggregate in the bulk solution to form micelles, a process that occurs at a characteristic concentration known as the critical micelle concentration (CMC). The CMC is a key parameter that reflects surfactant efficiency; lower CMC values indicate higher surface activity and reduced surfactant requirements for effective performance. Micelle formation enables the solubilization of hydrophobic compounds within the micellar core, which is essential for detergency and drug delivery applications.

- **Types of Surfactants by Charge**

Based on the nature of the hydrophilic head group, surfactants are classified into anionic, cationic, 1.

1. Classification Based on Hydrophilic Head Group

Surfactants are classified according to the nature of the electrical charge present on their hydrophilic head group, as this charge determines their physicochemical behavior, compatibility with other ingredients, and suitability for specific applications.

2. Anionic Surfactants

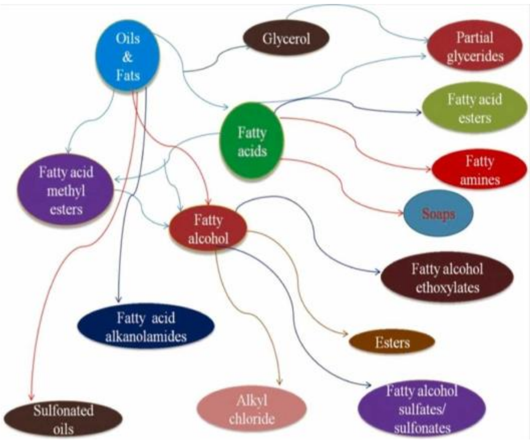
Anionic surfactants carry a negatively charged head group when dissolved in water. They are the most extensively used class due to their strong detergency, high foaming capacity, and excellent dirt and grease removal properties. These surfactants are commonly employed in household detergents, laundry powders, shampoos, and industrial cleaners. Common examples of anionic surfactants include dioctyl sodium sulfosuccinate (DOSS), which is employed as a wetting and dispersing agent in coatings and toothpaste, linear alkylbenzene sulfonates (LASs) used predominantly in laundry and dishwasher detergents, and sodium lauryl ether sulfate (SLES), a key ingredient in shampoos and bath products. Structurally, anionic surfactants can be classified into several subtypes, including soaps ($C_nH_{2n+1}COO^{-}X$), linear alkylbenzene sulfonates ($C_nH_{2n+1}SO_3^{-}X$), alkyl ether sulfates ($C_nH_{2n+1}(OCH_2CH_2)_nOSO_3X$), and alcohol sulfates ($R{-}OSO_3X$). Overall, anionic surfactants are generally considered to exhibit relatively low toxicity, which supports their widespread use in consumer and industrial applications.

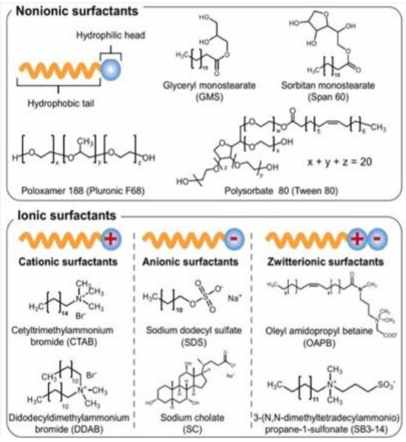
3. Cationic Surfactants

Cationic surfactants possess a positively charged head group and exhibit strong attraction toward negatively charged surfaces such as fabrics, hair, and microbial cell membranes. As a result, they are widely used for antimicrobial applications, fabric softeners, corrosion inhibitors, and hair-conditioning products, although their cleaning efficiency is generally lower than that of anionic surfactants. Common examples of cationic surfactants include methylbenzethonium and benzalkonium quaternary ammonium compounds. Structurally, this class includes quaternary ammonium compounds (QACs; $R_1R_2R_3R_4N^+X^-$), ester-based QACs [$RCO–O–CH_2CH_2–N(CH_3)_2^+$], and derivatives of pyridines and imidazolines [$NC_5H_5^+ \cdot R_1–C{=}N–(CH_2)_2–N–R_2^+$].

4. Nonionic Surfactants

Nonionic surfactants do not carry any formal electrical charge and achieve water solubility through hydrogen bonding. They are highly stable across a wide range of pH levels and water hardness conditions, making them suitable for industrial processes, food formulations, pharmaceuticals, and agricultural applications



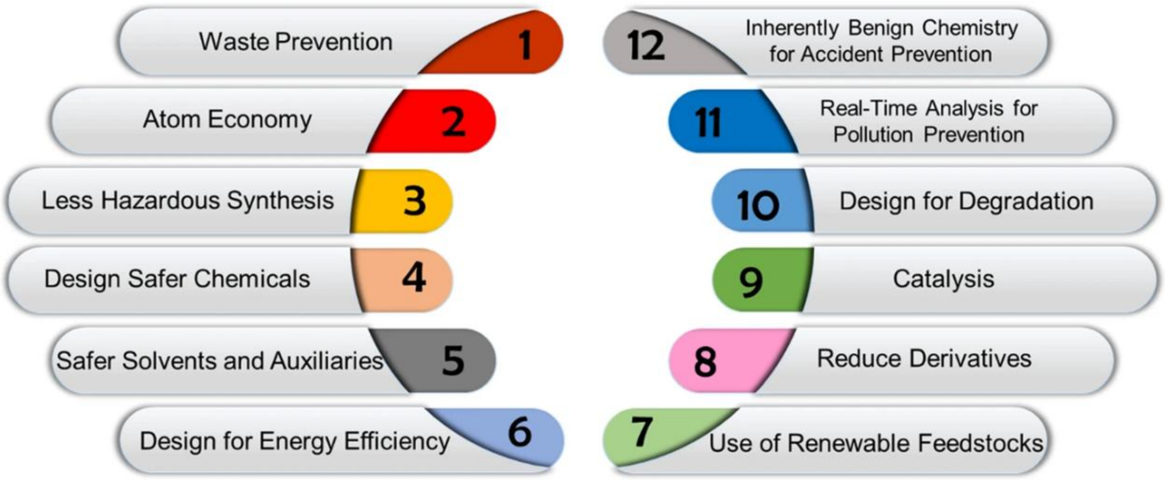


5. Zwitterionic Surfactants

Zwitterionic surfactants contain both positive and negative charges within the same molecule. They are known for their exceptional mildness, low irritation potential, and high biocompatibility, which makes them ideal for personal care, cosmetic, and biomedical applications.

Green Chemistry Principles in Bio-based Surfactant Synthesis

The twelve principles of green chemistry provide a foundational framework for the sustainable design and synthesis of bio-based surfactants, aiming to minimize environmental impact while maintaining functional efficiency. Waste prevention is emphasized by designing processes that reduce or eliminate by-products during surfactant synthesis. Atom economy encourages the incorporation of all raw materials into the final product, which is particularly relevant in esterification and enzymatic reactions used for bio-based surfactants. The principle of less hazardous chemical synthesis promotes the avoidance of toxic reagents and intermediates, ensuring safer production and reduced risk to human health. Designing safer chemicals ensures that the resulting surfactants perform effectively while exhibiting low toxicity and high biodegradability. Safer solvents and auxiliaries advocate the use of water or benign solvents instead of volatile organic compounds. Energy efficiency is achieved by conducting reactions at ambient temperature and pressure, especially in microbial and enzymatic synthesis routes. The use of renewable feedstocks underpins bio-based surfactant production, relying on plant oils, sugars, and biomass instead of fossil resources. Reduction of derivatives minimizes unnecessary protection and modification steps, lowering waste and energy consumption. Catalysis, particularly through enzymes and reusable catalysts, enhances reaction selectivity and efficiency. Design for degradation ensures that surfactants break down into non-toxic substances after use, preventing environmental persistence. Real-time analysis for pollution prevention allows monitoring and control of processes to avoid hazardous releases. Finally, inherently safer chemistry for accident prevention reduces risks associated with chemical handling and storage. Collectively, these principles guide the development of bio-based surfactants that align with sustainability goals, regulatory requirements, and the growing demand for environmentally responsible products.



The Twelve Principles of Green Chemistry Applied to the Synthesis of Bio-based Surfactants. This figure illustrates the twelve core principles of green chemistry—waste prevention, atom economy, less hazardous chemical synthesis, design of safer chemicals, safer solvents and auxiliaries, energy efficiency, use of renewable feedstocks, reduction of derivatives, catalysis, design for degradation, real-time analysis for pollution prevention, and inherently benign chemistry for accident prevention—which collectively guide the sustainable design and synthesis of bio-based and biodegradable surfactants. *(Adapted from: A review on the synthesis of bio-based surfactants using green chemistry principles).*

Literature Review

The growing emphasis on sustainability and environmental protection has driven extensive research into green and bio-based surfactants, particularly those synthesized using green chemistry principles. Stubbs et al. (2022) provide a comprehensive review highlighting how renewable feedstocks, benign solvents, and energy-efficient synthesis routes can significantly reduce the environmental footprint of surfactant production. Their work emphasizes the alignment of bio-based surfactant synthesis with the twelve principles of green chemistry, especially waste prevention, atom economy, and design for degradation. The authors critically discuss chemical and biochemical synthesis routes, noting that enzymatic and microbial processes often outperform conventional petrochemical methods in terms of biodegradability and toxicity, although challenges related to scalability and cost remain. This foundational review establishes a theoretical and methodological framework for understanding sustainable surfactant development.

Expanding on sustainability comparisons, Nagtode et al. (2023) present an in-depth evaluation of biosurfactants as petroleum-free alternatives, focusing on performance, market potential, and future prospects. Their study compares biosurfactants with conventional surfactants across parameters such as surface activity, environmental impact, and economic feasibility. The authors highlight that biosurfactants often exhibit superior biodegradability, lower eco-toxicity, and multifunctional properties, including antimicrobial and emulsifying capabilities. Similarly, Le Guenic et al. (2019) explore renewable surfactants derived from carbohydrates and lipids, emphasizing their relevance in biochemical and nanotechnological applications. Their findings demonstrate that carbohydrate-based surfactants offer high biocompatibility and tunable molecular structures, making them particularly suitable for sensitive and high-value applications, despite higher production complexity.

Several studies have focused on application-specific performance of green surfactants, particularly in environmental and industrial remediation. Ziaee et al. (2021) report the synthesis of a green surfactant for treating water contaminated with PFAS and hazardous metal ions, demonstrating effective contaminant removal through enhanced solubilization and complexation mechanisms. Their results highlight the dual functionality of green surfactants in addressing both organic and inorganic pollutants, reinforcing their potential in water treatment technologies. In another industrial context, Verma et al. (2023) examine the design and application of green surfactants for corrosion control. Their review underscores how bio-based surfactants can act as efficient corrosion inhibitors while minimizing environmental hazards, offering a sustainable alternative for metal protection in harsh industrial environments. Wang et al. (2021) further extend the application scope by discussing the role of surfactants in the papermaking industry, where green surfactants contribute to improved process efficiency, reduced effluent toxicity, and compliance with stricter environmental regulations.

From a broader historical and technological perspective, Benvegnu et al. (2008) provide early insights into surfactants derived from renewable resources, laying the groundwork for later advancements in bio-based surfactant chemistry. Their work underscores the long-standing potential of renewable feedstocks, even though large-scale adoption was limited at the time due to economic constraints. More recent studies, such as that by Rad et al. (2023), demonstrate how these earlier concepts are now being translated into advanced applications like foam-based enhanced oil recovery (EOR). Rad et al. synthesize a biocompatible surfactant and validate its feasibility in EOR, showing promising performance in terms of foam stability and oil displacement efficiency. Collectively, these studies indicate a clear progression from conceptual development to application-driven research, while also identifying persistent challenges related to cost reduction, large-scale production, and market penetration.

Green and Biodegradable Surfactants

- **Definition and Criteria for “Green” Surfactants**

Green surfactants are surface-active agents designed to deliver effective interfacial performance while minimizing adverse environmental and health impacts throughout their life cycle, from raw material sourcing to end-of-life degradation. They are typically derived from renewable resources, synthesized using environmentally benign processes, and capable of rapid and complete biodegradation into non-toxic products.

1. Biodegradability Standards: A core criterion for green surfactants is compliance with recognized biodegradability standards, such as those outlined in OECD 301 and 302 guidelines, which assess ready and inherent biodegradation under controlled conditions. Surfactants meeting these standards demonstrate efficient microbial breakdown within a defined time frame, reducing persistence and accumulation in ecosystems.

2. Toxicity and Eco-toxicity Criteria: In addition to biodegradability, green surfactants must exhibit low toxicity toward aquatic and terrestrial organisms, including algae, invertebrates, and fish, as well as minimal cytotoxicity for human exposure. Eco-toxicity evaluations emphasize acute and chronic effects, endocrine disruption potential, and bioaccumulation tendencies, ensuring environmental safety even at higher usage levels.

3. Regulatory Drivers: Regulatory frameworks and policy initiatives strongly influence the development and adoption of green surfactants. Organizations such as the OECD, REACH in the European Union, and the United States Environmental Protection Agency (EPA) establish guidelines and restrictions that encourage the replacement of hazardous surfactants with safer alternatives, driving innovation toward sustainable chemistries.

- **Classification of Green Surfactants**

Green and biodegradable surfactants can be broadly classified based on their origin and synthesis approach.

1. Biosurfactants (Microbial, Enzymatic): Biosurfactants are produced by microorganisms such as bacteria, yeasts, and fungi through fermentation processes, and include glycolipids, lipopeptides, phospholipids, and polymeric surfactants. These materials are valued for their high biodegradability, low toxicity, and effectiveness under extreme pH, temperature, and salinity conditions.

2. Bio-based Surfactants (Plant/Animal Derived): Bio-based surfactants are synthesized from renewable plant or animal feedstocks, including fatty acids, sugars, and amino acids, using chemical or enzymatic routes aligned with green chemistry principles. Examples include alkyl polyglucosides and fatty acid esters, which combine good surface activity with environmental compatibility.

3. Novel Synthetic Biodegradable Surfactants: This category includes newly designed surfactants engineered at the molecular level to achieve controlled biodegradability and enhanced performance. Such surfactants often employ cleavable linkages, tailored head groups, and optimized hydrophobic chains to balance efficiency, stability, and environmental safety, representing a promising direction for next-generation sustainable surfactant technologies.

Synthesis of Green Surfactants

1. Microbial Biosynthesis: Microbial biosynthesis represents one of the most sustainable routes for producing green surfactants, as it relies on renewable substrates and mild operating conditions.

Glycolipids (rhamnolipids, sophorolipids, trehalolipids): Glycolipid biosurfactants are produced by various microorganisms such as *Pseudomonas*, *Candida*, and *Rhodococcus* species through fermentation processes. These compounds consist of carbohydrate head groups linked to fatty acid chains and exhibit excellent surface activity, biodegradability, and low toxicity.

Lipopeptides and Lipoamino Acids: Lipopeptides, produced mainly by *Bacillus* species, comprise peptide-based hydrophilic heads and lipid tails, offering strong emulsifying properties and antimicrobial activity. Lipoamino acid surfactants similarly combine amino acids with fatty chains, enhancing biocompatibility and functional versatility.

Fermentation Optimization Strategies: To improve yield and economic feasibility, fermentation parameters such as carbon source selection, pH, temperature, aeration, and nutrient composition are optimized, often using agro-industrial waste as feedstock to further enhance sustainability.

2. Chemical Synthesis of Bio-based Surfactants: In addition to microbial routes, bio-based surfactants can be synthesized chemically from renewable raw materials such as plant oils, sugars, and fatty acids.

Esterification and Transesterification Routes: These methods involve the reaction of fatty acids or triglycerides with alcohols or polyols to produce ester-based surfactants, which are readily biodegradable and widely used in detergents and cosmetics.

Etherification and Ring-Opening Methods: Etherification of bio-derived alcohols and ring-opening polymerization of cyclic compounds enable the production of nonionic surfactants with controlled hydrophilic–lipophilic balance and enhanced stability.

Enzymatic Catalysis: The use of enzymes such as lipases offers high selectivity, reduced energy consumption, and minimal by-product formation, aligning well with green chemistry principles.

3. Novel Synthetic Strategies: Advanced synthetic approaches are increasingly employed to tailor surfactant performance and sustainability.

Click Chemistry for Tailored Head/Tail Groups: Click chemistry enables precise molecular design through highly efficient and selective reactions, allowing the customization of surfactant architecture with minimal waste.

Polymerizable Surfactants: These surfactants can undergo polymerization after self-assembly, offering improved stability and functionality in specialized applications.

4. Green Chemistry Metrics in Synthesis: Evaluating synthesis routes using green chemistry metrics is essential for sustainability assessment.

Atom Economy: High atom economy indicates efficient incorporation of raw materials into the final product.

E-factor and Process Mass Intensity (PMI): Low E-factor and PMI values reflect reduced waste generation and material consumption.

Solvent Selection and Life Cycle Considerations: The use of benign solvents and life cycle assessment ensures minimized environmental impact across production, use, and disposal stages.

Applications of Green and Biodegradable Surfactants

- **Personal Care and Cosmetics**

Green and biodegradable surfactants are extensively used in personal care and cosmetic formulations due to their mildness, skin compatibility, and low environmental impact.

1. Shampoos, Cleansers, and Skin Formulations: Bio-based and biosurfactants such as alkyl polyglucosides, amino acid surfactants, and sophorolipids are commonly incorporated into shampoos, facial cleansers, body washes, and skincare products, where they provide effective cleansing, foaming, and emulsification while maintaining skin moisture and barrier integrity. **2. Mildness and Irritation Studies:** These surfactants demonstrate reduced eye and skin irritation compared to conventional surfactants, making them suitable for sensitive-skin and baby-care formulations, as supported by dermatological and toxicological studies.

- **Household and Industrial Cleaning**

In household and industrial cleaning applications, green surfactants offer efficient dirt removal with improved environmental safety.

1. Laundry and Dishwashing Systems: Biodegradable surfactants are increasingly used in laundry detergents and dishwashing liquids to deliver strong detergency, stain removal, and foam control while reducing aquatic toxicity and wastewater treatment burden.

2. Hard Surface Cleaners: In industrial and institutional cleaning, these surfactants effectively remove oils, greases, and particulates from hard surfaces, contributing to safer indoor environments and reduced chemical exposure.

- **Agricultural Formulations**

Green surfactants play a critical role in improving the efficiency and sustainability of agricultural inputs.

1. Pesticide Adjuvants and Wetting Agents: They enhance the spreading, adhesion, and penetration of pesticides and fertilizers on plant surfaces, thereby reducing chemical usage and environmental runoff.

2. Soil Remediation Enhancement: Biosurfactants facilitate the mobilization and biodegradation of hydrophobic contaminants in soils, improving the effectiveness of in situ remediation strategies.

- **Enhanced Oil Recovery (EOR) and Petroleum Applications**

In the energy sector, green surfactants offer environmentally responsible alternatives for oil recovery processes.

1. Wettability Alteration and Microemulsions: Biosurfactants are used to alter reservoir wettability and form stable microemulsions that enhance oil displacement efficiency.

2. Field-scale Performance and Economics: Although cost remains a challenge, advances in fermentation and scale-up have improved the economic viability of biosurfactants for field-scale EOR applications.

- **Biomedical and Pharmaceutical Use**

The biocompatibility of green surfactants makes them suitable for medical and pharmaceutical applications.

1. Drug Delivery and Nanocarrier Systems: They are employed in the formulation of drug delivery systems and nanocarriers to improve solubility, stability, and bioavailability of active pharmaceutical ingredients.

2. Antimicrobial and Therapeutic Surfactants: Certain biosurfactants exhibit inherent antimicrobial, antiviral, and anti-inflammatory properties, enabling therapeutic and preventive healthcare applications.

- **Environmental Remediation**

Environmental protection is a major application area for green surfactants.

Oil Spill Dispersion: Biosurfactants are used to disperse oil spills by enhancing oil solubilization and biodegradation in marine environments.

Heavy Metal Mobilization and Removal: They also aid in mobilizing and removing heavy metals from contaminated soils and water, supporting sustainable and eco-friendly remediation technologies.

Conclusion

Green and biodegradable surfactants represent a vital advancement toward sustainable chemical technologies, addressing the environmental and health challenges associated with conventional petrochemical-based surfactants. This study has highlighted that surfactants derived from renewable resources and synthesized through green chemistry and biotechnological approaches can deliver effective surface activity while significantly reducing ecological impact. Microbial biosynthesis, enzymatic catalysis, and bio-based chemical routes have been shown to produce surfactants with high biodegradability, low toxicity, and functional versatility. Their successful application across diverse sectors—including personal care, household and industrial cleaning, agriculture, petroleum recovery, biomedical formulations, and environmental remediation—demonstrates their broad potential and growing industrial relevance. Comparative sustainability assessments further indicate that, despite higher initial production costs and scale-up challenges, green surfactants offer long-term benefits through reduced carbon footprint, improved regulatory compliance, and enhanced consumer acceptance. Regulatory frameworks and market trends increasingly favor environmentally benign formulations, accelerating research and innovation in this field. However, challenges related to economic feasibility, process optimization, and consistent product quality remain critical barriers to widespread commercialization. Continued advancements in fermentation technology, renewable feedstock utilization, and molecular design are essential to overcome these limitations. Overall, the transition toward green and biodegradable surfactants is not only scientifically feasible but also environmentally and economically necessary, supporting sustainable industrial practices and contributing to global efforts aimed at environmental protection and circular economy development.

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